

Exhibit C

U.S. Patent No. 6,744,818

Method and Apparatus for Visual Perception Encoding



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Sheraizin et al.

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(54) **METHOD AND APPARATUS FOR VISUAL PERCEPTION ENCODING**

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(52) **U.S. Cl.** **375/240.29**

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Primary Examiner—Young Lee

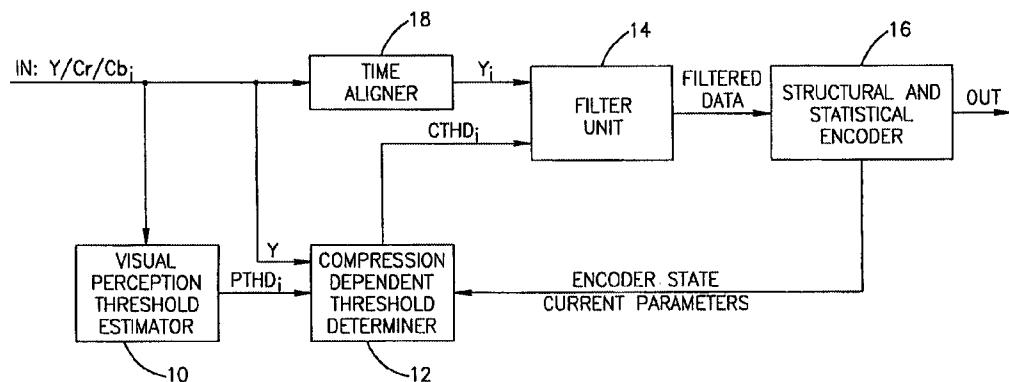
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(57)

ABSTRACT

A video encoding system includes a visual perception estimator, an encoder, a compression dependent threshold estimator and a filter unit. The visual perception estimator estimates a perception threshold for a pixel of a current frame of a videostream. The encoder encodes the current frame. The compression dependent threshold estimator estimates a compression dependent threshold for the pixel at least from the perception threshold and information from the encoder. The filter unit filters the pixel at least according to the compression dependent threshold.

9 Claims, 12 Drawing Sheets



US 6,744,818 B2

Page 2

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U.S. Patent

Jun. 1, 2004

Sheet 1 of 12

US 6,744,818 B2

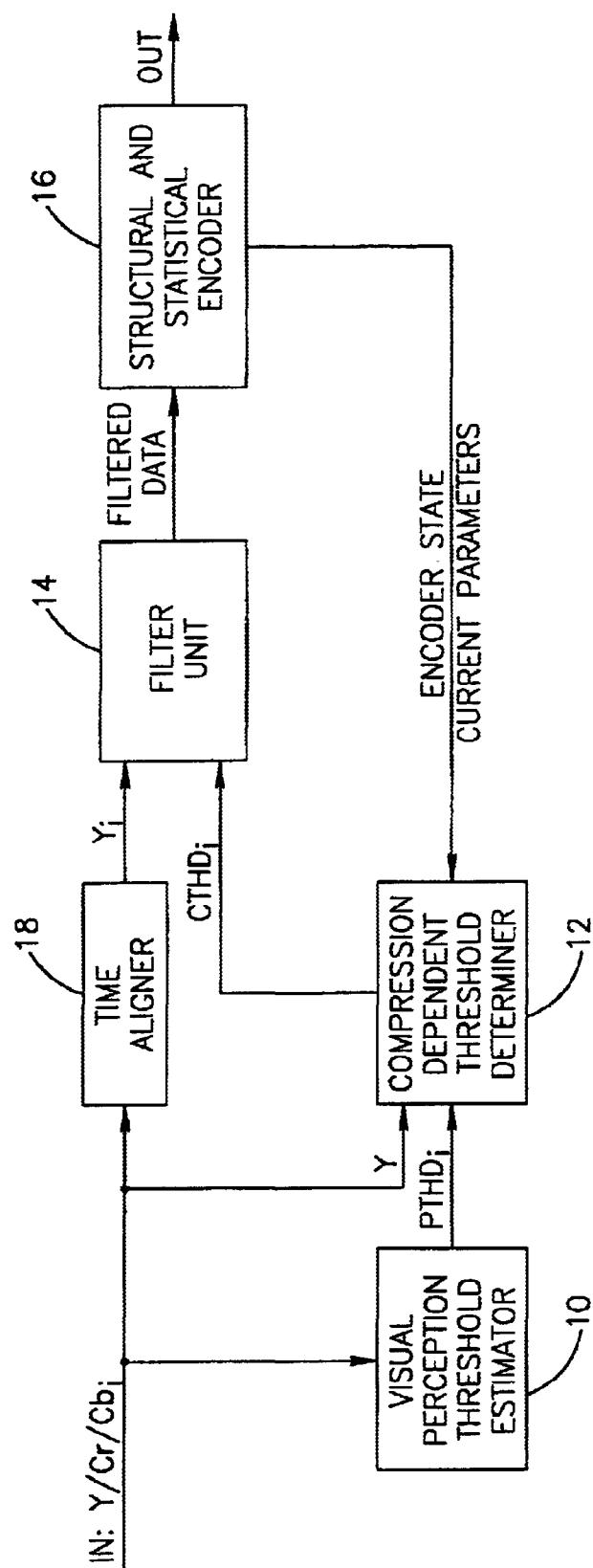


FIG. 1

U.S. Patent

Jun. 1, 2004

Sheet 2 of 12

US 6,744,818 B2

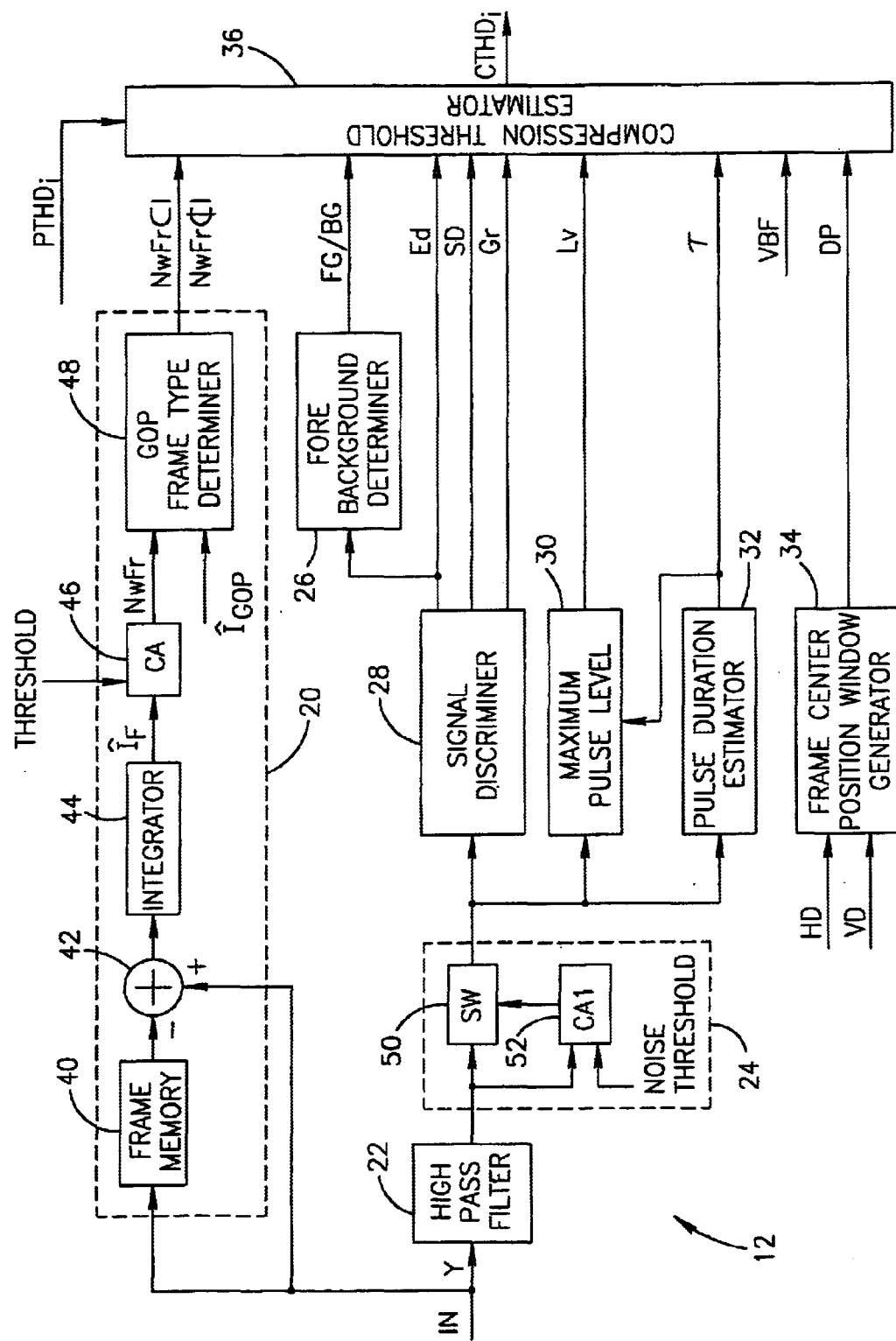


FIG. 2

U.S. Patent

Jun. 1, 2004

Sheet 3 of 12

US 6,744,818 B2

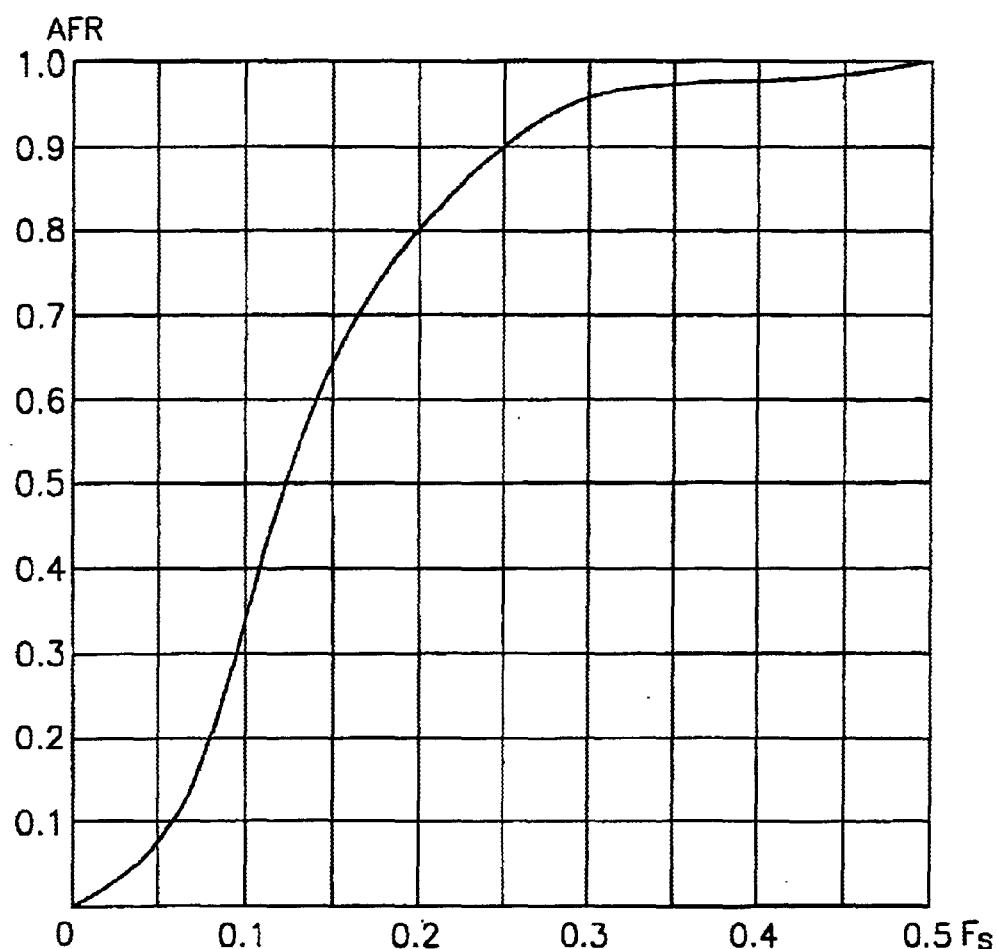


FIG.3

U.S. Patent

Jun. 1, 2004

Sheet 4 of 12

US 6,744,818 B2

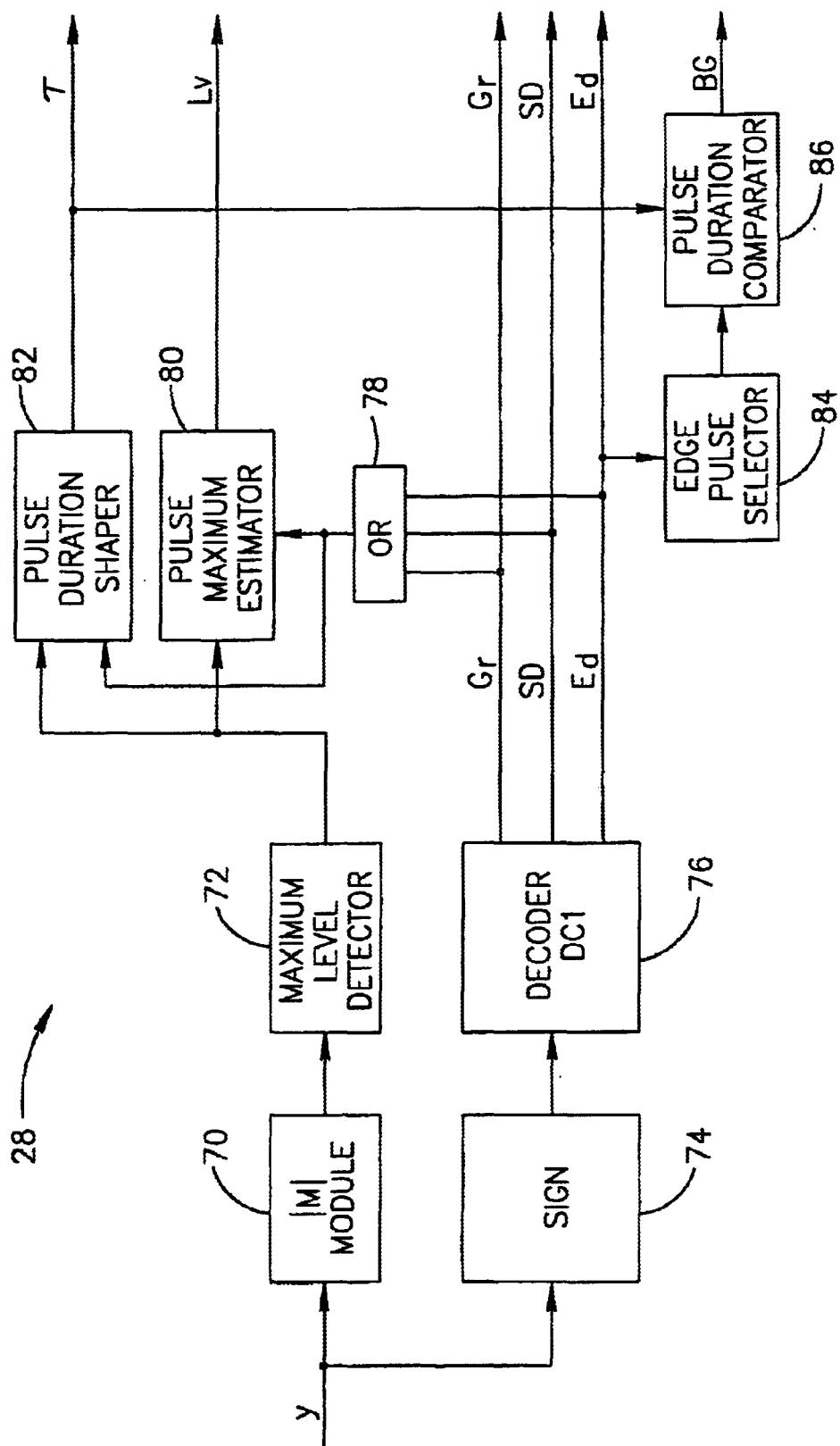


FIG. 4

U.S. Patent

Jun. 1, 2004

Sheet 5 of 12

US 6,744,818 B2

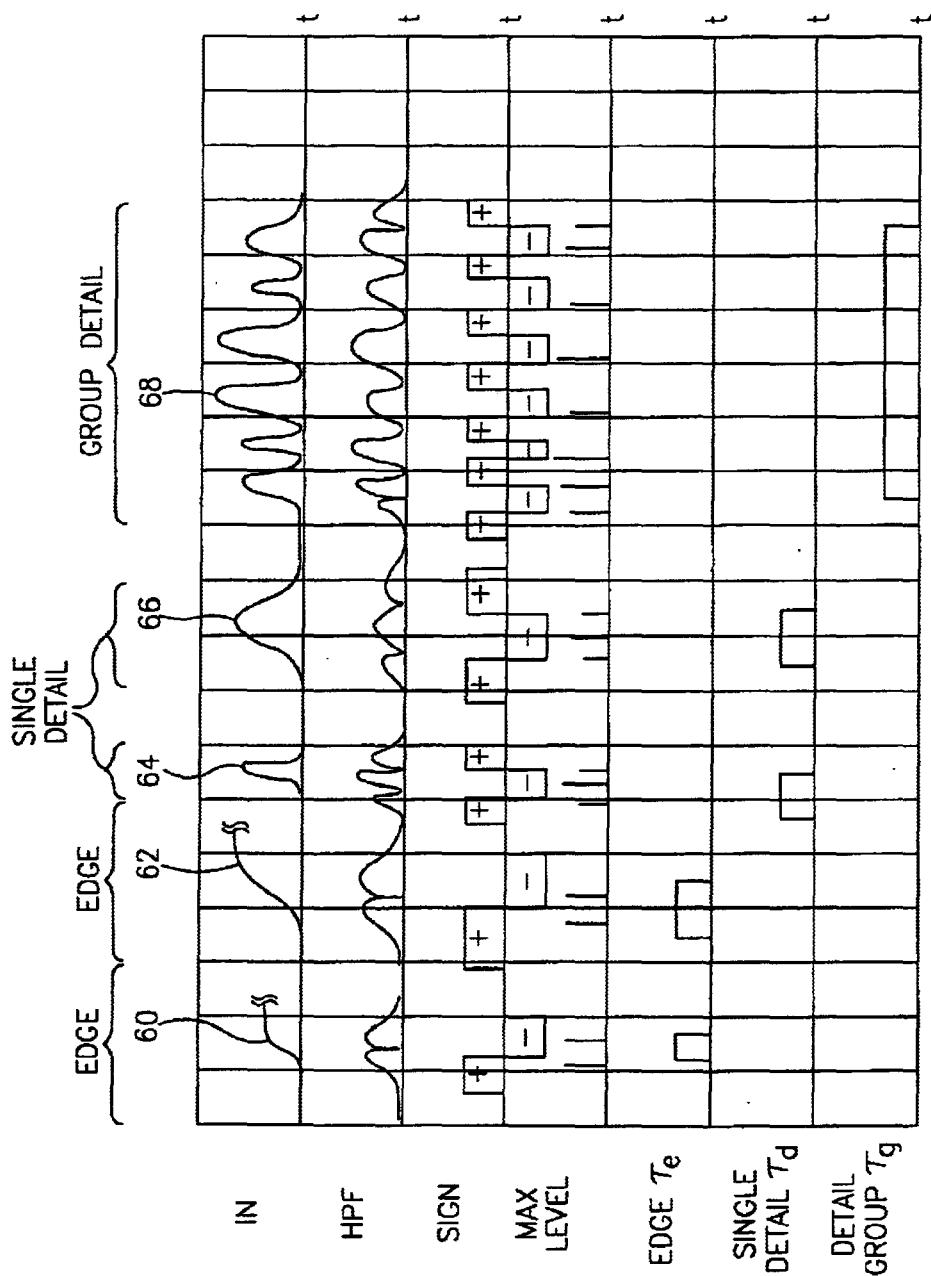


FIG. 5

U.S. Patent

Jun. 1, 2004

Sheet 6 of 12

US 6,744,818 B2

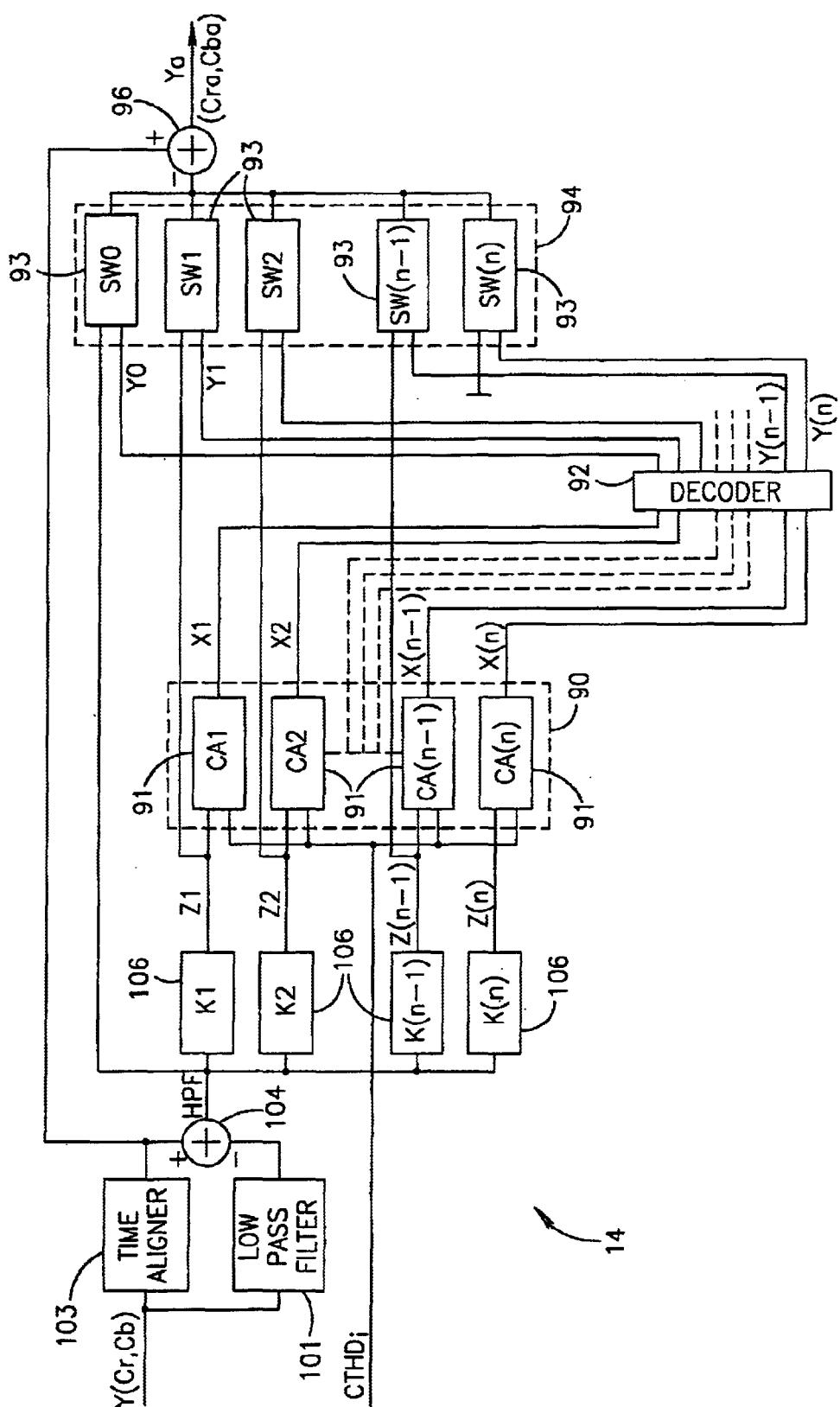


FIG. 6

U.S. Patent

Jun. 1, 2004

Sheet 7 of 12

US 6,744,818 B2

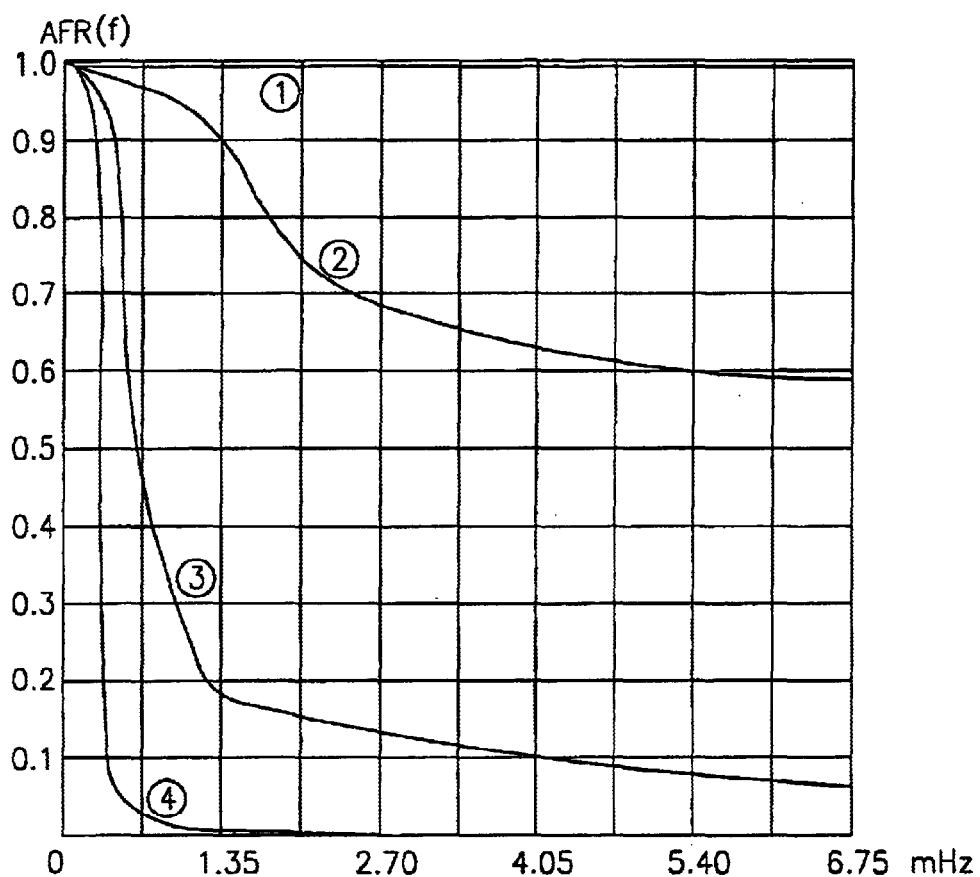


FIG.7

U.S. Patent

Jun. 1, 2004

Sheet 8 of 12

US 6,744,818 B2

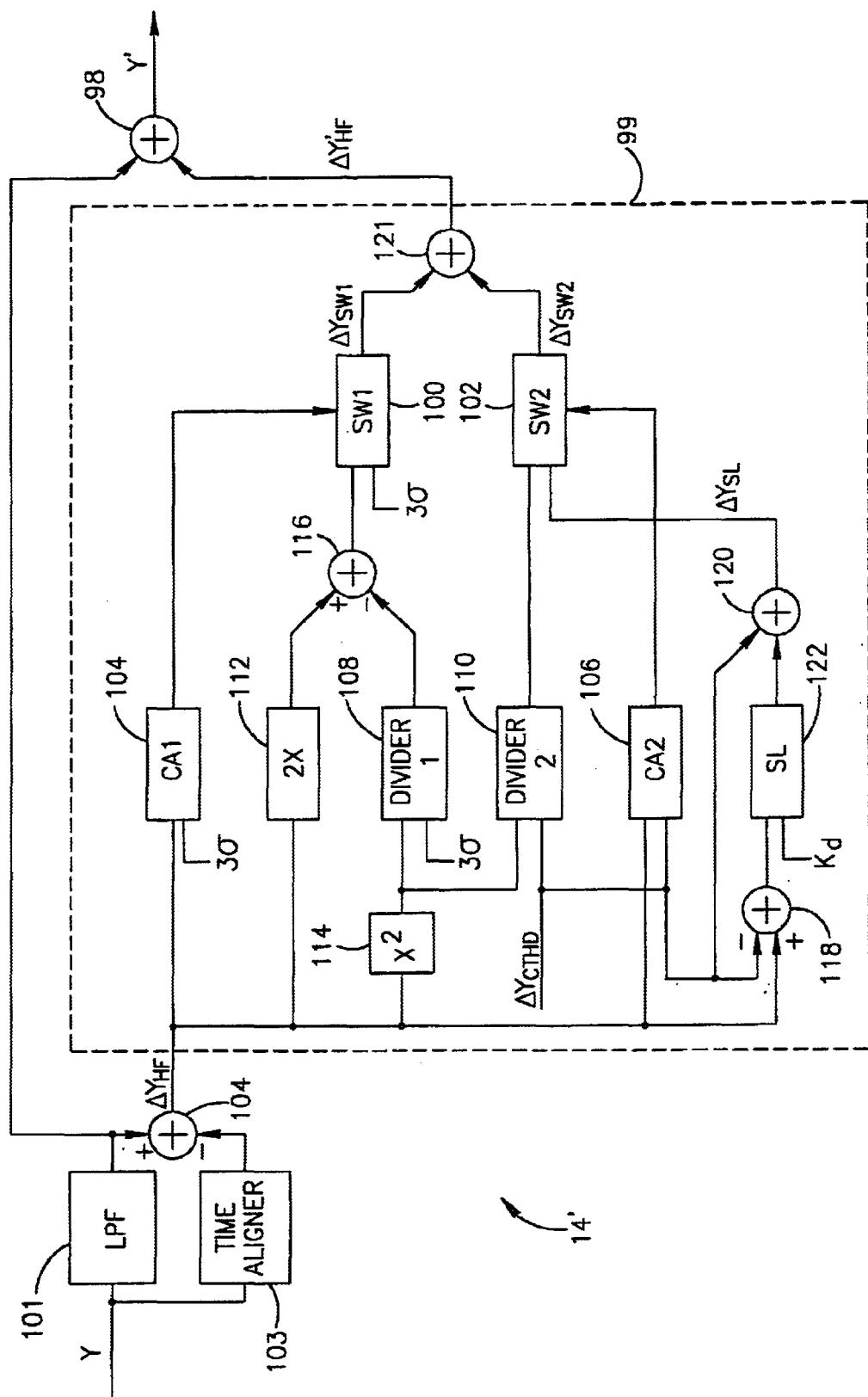


FIG. 8

U.S. Patent

Jun. 1, 2004

Sheet 9 of 12

US 6,744,818 B2

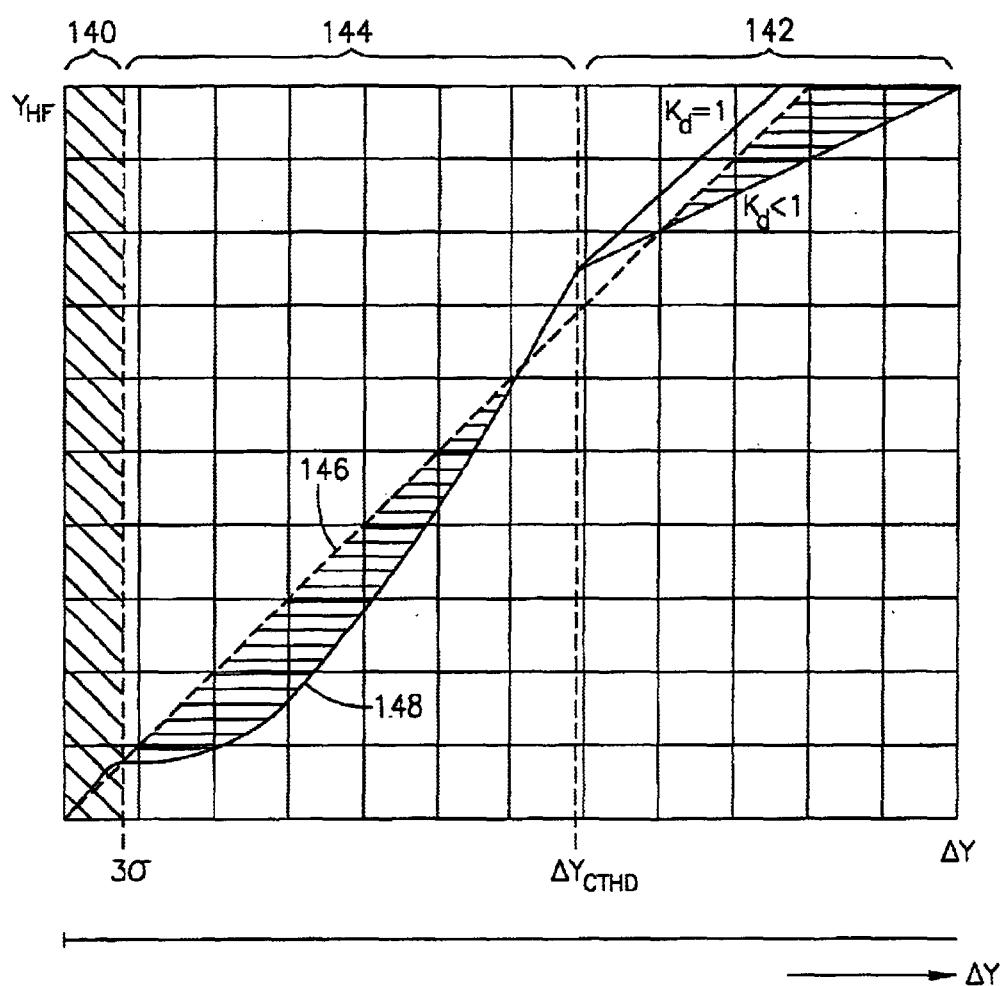


FIG.9

U.S. Patent

Jun. 1, 2004

Sheet 10 of 12

US 6,744,818 B2

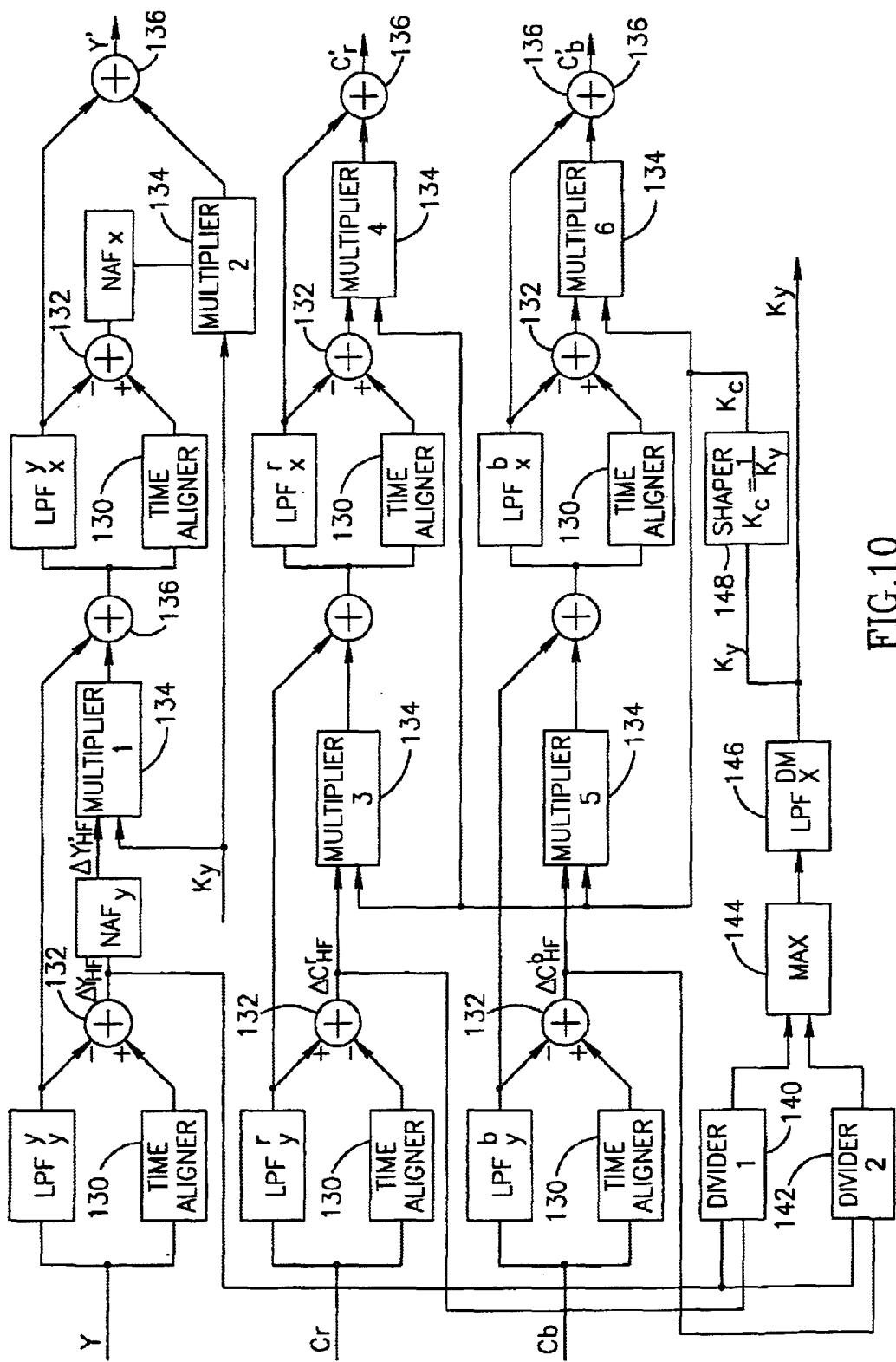


FIG.10

U.S. Patent

Jun. 1, 2004

Sheet 11 of 12

US 6,744,818 B2

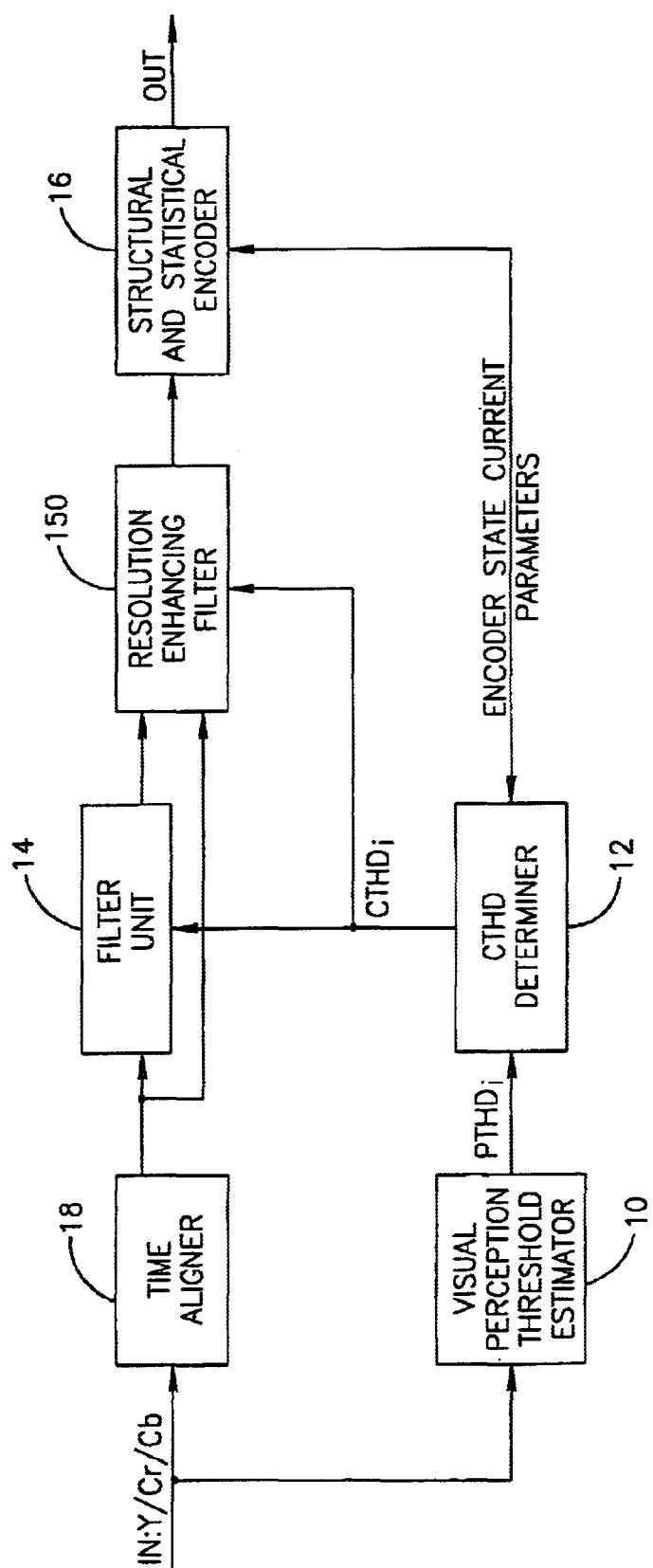


FIG.11

U.S. Patent

Jun. 1, 2004

Sheet 12 of 12

US 6,744,818 B2

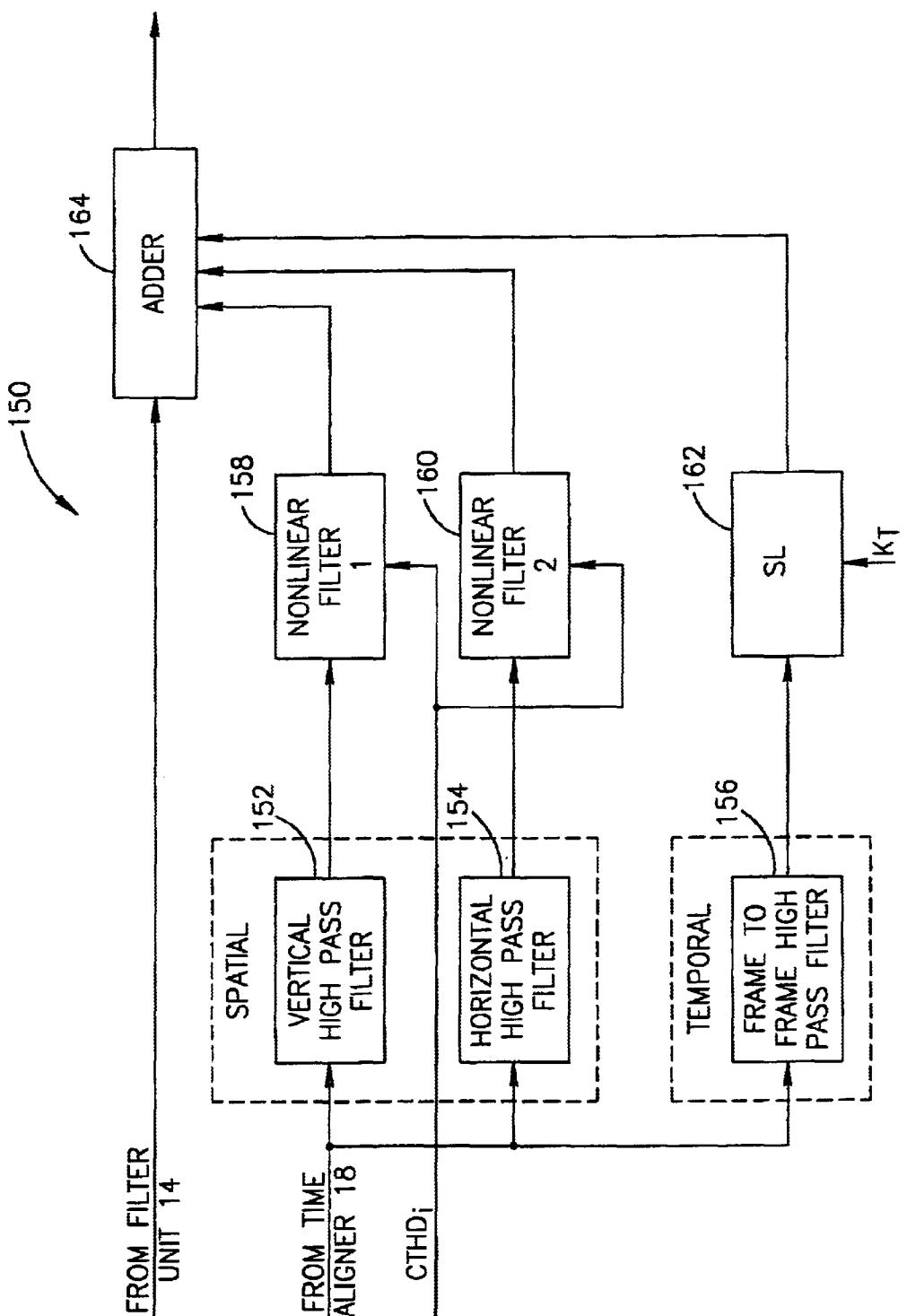


FIG.12

US 6,744,818 B2

1**METHOD AND APPARATUS FOR VISUAL PERCEPTION ENCODING****FIELD OF THE INVENTION**

The present invention relates generally to processing of video images,

BACKGROUND OF THE INVENTION

There are three types of redundancy in video signals that are related to the picture within the video. These are structural, statistical and perceptual redundancy. Standard compression systems, such as the various forms of MPEG, H-compression, etc., mainly reduce structural and statistical redundancy. U.S. patent application Ser. No. 09/524,618, assigned to the common assignees of the present invention and incorporated herein by reference, attempts to reduce perceptual redundancy independent of whatever other video compression might be used afterward.

BRIEF DESCRIPTION OF THE DRAWINGS

The present invention will be understood and appreciated more fully from the following detailed description taken in conjunction with the appended drawings in which:

FIG. 1 is a block diagram illustration of a system for visual perception encoding, for use with standard compression encoders, constructive and operative in accordance with a preferred embodiment of the present invention;

FIG. 2 is a block diagram illustration of a compression dependent threshold determiner, useful in the system of **FIG. 1**;

FIG. 3 is a graph of the response of a high pass filter, useful in the determiner of **FIG. 2**;

FIG. 4 is a block diagram illustration of a signal discriminator, useful in the determiner of **FIG. 2**;

FIG. 5 is a timing diagram illustration, useful in understanding the operation of the determiner of **FIG. 2**;

FIG. 6 is a block diagram illustration of a filter unit, useful in the system of **FIG. 1**;

FIG. 7 is a graphical illustration of the frequency response of the filter unit of **FIG. 6**;

FIG. 8 is a block diagram illustration of an alternative, non-linear filter, useful in the system of **FIG. 1**;

FIG. 9 is a graphical illustration of the frequency response of the filter unit of **FIG. 8**;

FIG. 10 is a block diagram illustration of an alternative filter unit utilizing the non-linear filter of **FIG. 8**, useful in the system of **FIG. 1**;

FIG. 11 is a block diagram illustration of a system for visual perception encoding having a resolution enhancing filter, constructive and operative in accordance with an alternative preferred embodiment of the present invention; and

FIG. 12 is a block diagram illustration of the resolution enhancing filter of **FIG. 11**.

DETAILED DESCRIPTION OF THE PRESENT INVENTION

Reference is now made to **FIG. 1**, which illustrates a video encoding system, constructed and operative in accordance with a preferred embodiment of the present invention. The encoding system generally reduces perceptual redundancy in video streams and may comprise a visual perception

2

threshold estimator **10**, a compression dependent threshold determiner **12**, a filter unit **14** and a structural and statistical encoder **16**.

Visual perception threshold estimator **10** may receive an image having luminance Y and red and blue chrominance Cr and Cb signals and may estimate a distinguishing visual perception threshold PTHD_i for each ith pixel of the image. An exemplary estimator **10** is described in U.S. patent application Ser. No. 09/524,618, filed Mar. 14, 2000, assigned to the common assignees of the present invention and incorporated herein by reference.

Compression dependent threshold determiner **12** may estimate a distinguishing compression dependent threshold CTHD_i for the ith pixel using the luminance values Y of the image, visual perception threshold PTHD_i and information from encoder **16** about the type of image the current image is as will be described in more detail hereinbelow.

Filter unit **14** filters the ith pixel based on the value of the associated compression dependent threshold CTHD_i. It can be a controllable filter set (shown in **FIG. 6**) or a nonlinear filter (shown in **FIGS. 8 and 10**). Thus, the kind of filtering to be performed on a pixel depends on whether the luminance value Y of that pixel is above or below the specific distinguishing threshold for that pixel. Since estimator **10** and determiner **12** typically operate with a time delay, the encoding system comprises a time aligner **18** which provides the ith pixel of the image to filter unit **14** when filter unit **14** receives the ith compression dependent threshold CTHD_i.

The filtered data is then provided to encoder **16** for standard encoding. Typically, encoder **16** is a structural and statistical encoder such as any of the MPEG types or an H compression encoder. As is known in the art, MPEG encoders divide the frames of the videotream into "I", "P" and "B" compressed frames where I frames are compressed in full while, for the p and B images, only the differences between the current frame and previous predicted frames are encoded. The type of the frame (i.e. was it an I, P or B frame?) is provided to threshold determiner **12** for use in determining the compression dependent threshold CTHD_i. Thus, the type of encoding which encoder **16** performed at least partially affects the type of filtering which filter set **14** will ultimately perform.

Reference is now made to **FIG. 2**, which generally details the elements of compression dependent threshold determiner **12**. Determiner **12** comprises a new frame determiner **20**, a high pass filter **22**, a noise reducer **24**, various parameter determiners **26-34** and a compression threshold estimator **36**. The parameters defining the CTHD value comprise at least some of the following parameters:

- 50 whether or not encoder **16** has defined a new frame NwFr as an I frame;
- whether the ith pixel is in the foreground FG or the background BG of the picture;
- whether the ith pixel forms part of an edge Ed around an object in the picture;
- whether or not the ith pixel forms part of a small detail SD;
- whether or not the ith pixel is part of a group Gr type of details (a set of generally periodic details);
- the contrast level Lv of the detail for the ith pixel;
- the duration τ (in transmission time) of a detail within a picture;
- how full a video buffer of encoder **16** is full (a VBF value);
- the distance DP of the ith pixel from the center of the frame; and

US 6,744,818 B2

3

an initial value C_0 for compression dependent threshold CTHD.

The maximum pulse level Lv may be normalized by a maximum luminance signal NLv value, the pulse duration may be normalized by sampling internal Nt and the detail position DP may be defined by the number of lines and the pixel position within a line. Estimator 36 may then determine compression dependent threshold CTHD, from the normalized parameters and the visual perception threshold PTHDi as follows:

$$CTHD_i = \left(\frac{PTHD_i + C_E Ed + C_D SD + C_G Gr + C_r Nt +}{C_L NLv + C_F NwFr + C_B F/B + C_P DP} \right) C_V VBF + C_0$$

where C_E, C_D, \dots, C_P are weighting coefficients, dependent on the influence of each parameter at CTHD. For MPEG encoders, the following empirical values may be useful:

$$C_E = 0.2$$

$$C_D = 0.8$$

$$C_G = 0.1$$

$$C_L = 0.6$$

$$C_r = 0.6$$

$$C_F = \begin{cases} 0.7 & \text{if } NwFr = 1 \\ 0 & \text{otherwise} \end{cases}$$

$$C_B = \begin{cases} 0.5 & \text{if background} \\ 0 & \text{if foreground} \end{cases}$$

$$C_P = 0.5 \left[\left(\frac{t_H - 0.5H}{0.5H} \right)^2 + \left(\frac{t_V - 0.5V}{0.5V} \right)^2 \right]^{0.5}$$

$$C_V = 1.5$$

$$C_0 = 0.1$$

where t_H and t_V are the position, in time, of the pixel within a line (t_H) and a frame (t_V) and H and V are the line and frame numbers, respectively, and C_0 is the initial CTHD value.

The following other relationships are noted:

$$NLv = \frac{Lv}{L_{\max}}$$

$$Nt = \frac{\tau_{pix}}{\tau}$$

where L_{\max} is the maximum value for the luminance signal and τ_{pix} is the transmission time of one pixel.

New frame determiner 20 may determine whether there is a new frame NwFr and whether or not it has been defined by encoder 16 as an I frame. New frame determiner 20 typically comprises a frame memory 40, a summer 42, an integrator 44, a comparator 46 and a group of pictures (GOP) frame type determiner 48.

Summer 42 finds the differences between the present frame and a previous one stored in frame memory 40. Integrator 44 sums the differences across the frame to produce a change volume I_f , indicating the amount change between the neighboring frames. If comparator 46 determines that this change volume I_f is above a certain threshold (such as more than 50% of the maximum amount of pixels in a frame), comparator 46 defines that the present frame is a new frame NwFr.

4

If comparator 46 indicates that the present frame is a new frame NwFr, GOP frame type determiner 48 determines whether or not encoder 16 defined the frame as an I frame within the current group of pictures and provides this information to estimator 36.

High pass filter 22 filters the pixels of the current frame to select only those details of the picture which are of generally short duration such as edges, "single details" formed of only a few pixels and/or details which have a group structure,

An exemplary amplitude-frequency response for high pass filter 22 is provided in FIG. 3 to which reference is now briefly made. It is noted that the cutoff frequency is about $0.2F_s$ where F_s is the sampling frequency of an analog to digital converter (not shown) used to digitize the input signal.

Returning to FIG. 2, noise reducer 24 takes the output of high pass filter 22 and reduces the noise level. Reducer 24 comprises a comparator 52 and a switch 50. Comparator 52 compares the signal level of the filtered signal produced by high pass filter 22 with a noise threshold (typically 3–5 times an average noise level). Switch 50 only passes the filtered signal if its signal level is high enough, as indicated by comparator 52.

A signal discriminator 28 determines which pixels of the filtered and noise reduced signal belong to edges (Ed), single detail (SD) and group of details (Gr). FIG. 4 provides one embodiment of discriminator 28.

A foreground/background determiner 26 uses the edge information to determine if the current pixel is in the foreground or background, where a foreground object has sharp edges and a background object has blurred edges (i.e. ones of long duration).

A pulse duration estimator 32 measures the length of each pulse (which may occur over multiple pixels) to generate the duration T of a detail and a maximum pulse level determiner 30 uses the duration to determine the maximum pulse level Lv within the pulse duration.

A detail position generator 34 determines DP, how close the current pixel is to the center of the frame. To do this, generator 34 receives the frame synchronization, i.e. the horizontal drive (HD) and vertical drive (VD) signals, and the current pixel and uses this information to compare the location of the current pixel to that of the center pixel of the frame

FIG. 4 is one embodiment of some of the elements of FIG. 2 showing the operation on the high pass filtered and noise reduced signal, FIG. 5, to which reference is also made, is a timing diagram indicating how the elements of FIG. 4 operate on different types of input signals.

The first timing diagram of FIG. 5 shows three types of input signals: two edges 60 and 62, two single details 64 and 66 and a group detail 68. The second timing diagram shows the shape of the signals 60–68 after high pass filtering and noise reduction.

An absolute value module 70 (FIG. 4) finds the absolute value of each pixel and a maximum level detector 72 converts the current maximum level into sign pulses. The output of detector 72 is shown in the fourth timing diagram of FIG. 5. For edges 60 and 62, there are two points where a maximum occurs, as can be seen in the high pass filtered signal of the second timing diagram. The single detail 66 has three points of maximum while the group detail 68 has many of them, relatively regularly spaced.

A sign indicator 74 (FIG. 4) determines the sign (positive or negative) of the high pass filtered and noise reduced signal. The output of indicator 74 is shown in the third

US 6,744,818 B2

5

timing diagram of FIG. 5. For edges **60** and **62**, the sign changes from positive to negative, but after different lengths of time. For single details **64** and **66**, the sign changes from positive, to negative to positive, once again after different lengths of time. For group detail **68**, the sign continually changes between negative and positive.

A decoder **76** uses the output of sign indicator **74** to determine whether the current pixel or series of pixels is an edge, a single detail or a group detail according to the following table:

TABLE 1

	+/- or -/+	+/-/+ or -/+/-	+/-/+/-/+/ . . .
Edge	yes	no	no
Single Detail	no	yes	no
Group Detail	no	no	yes

The output of decoder **76** is shown in the fifth, sixth and seventh timing diagrams for edges **60** and **62**, single details **64** and **66**, and group detail **68**, respectively. It is noted that edge **60** is shorter than edge **62** and single detail **64** is shorter than single detail **66**.

A pulse level maximum estimator **80** receives the edge, single detail and group detail signals of the fifth, sixth and seventh timing diagrams and finds the maximum level Lv of the pulse for the signal which currently has a pulse.

A pulse duration shaper **82** receives the maximum pulse level position signal from detector **72** and the edge, single detail and group detail signals from OR element **78** after decoder **76** and finds the duration X for the signal which currently has a pulse. An edge pulse selector **84** uses the edge signal from decoder **76** and the signal from shaper **82** to select an edge duration pulse when an edge is present. The edge duration pulse selected by selector **84** is provided to a pulse duration comparator **86** which compares the pulse duration x for me current edge to a threshold level indicating the maximum pulse length which indicates a foreground edge. Any pulse length which is longer than the threshold indicates a background pixel and any which is shorter indicates a foreground pixel.

Reference is now made to FIGS. 6 and 7 which, respectively, illustrate the elements of filter unit **14** (FIG. 1) and the shapes of the filters which are utilized therein.

Filter unit **14** is a controllable filter set and typically comprises a series of high pass filters (described in more detail hereinbelow), a set of comparators **90**, a decoder **92** and a set of switches **94**. Each high pass filter has a different frequency response and has a comparator **91** and a switch **93** associated therewith. The associated comparator **91** compares the level of the filtered data (i.e. filtered pixel) to the compression dependent threshold CTHD₁ for the current pixel. Decoder **92** decides which filter output to utilize (based on which filtered data is above the compression dependent threshold CTHD_i) and instructs the appropriate switch **93** to pass that filter output for the current pixel.

For each pixel, a summer **96** subtracts the high pass filtered data output from the appropriate switch **93** from the non-filtered data of the frame. Thus, the level of each pixel is changed by the selected high pass filter. It will be appreciated that the operation of controlled filter set **14** is equivalent to a low pass filter optimization for every picture detail in accordance with the value of the compression dependent threshold CTHD_i.

The high pass filters are implemented in the embodiment of FIG. 6 from a low pass filter **101**, a time aligner **103**, a summer **104** and multipliers **106**. Summer **104** subtracts a

6

low pass filtered version of the original frame from the original frame and produces thereby a high pass filtered frame. The filtered frame is provided to each multiplier **106** which, in turn, multiplies the signal of the filtered frame, This has the effect of changing the shape of the high pass filter that operates on the frame. Thus, the output of multipliers **106** is a high pass filtered signal. FIG. 7 shows the frequency response of four of the high pass filters, labeled 1-4.

Table 2 provides the function of decoder **92**, for eight multipliers K1-K8 whose weight values are 0.125, 0.25, 0.375, 0.5, 0.625, 0.75, 0.875 and 1.0, respectively. Their outputs are signals z1-z8, respectively, the outputs of their respective comparators **91** are signals x1-x8, respectively, and the signals to their associated switches are y1-y8, respectively. The signal y0 instructs a switch sw0 to select the high pass filter output of summer **104**.

TABLE 2

High pass filter		K1 . . . K8							
signal level, Zi		X1	X2	X3	X4	X5	X6	X7	X8
Z8 < CTHD		0	0	0	0	0	0	0	0
Z8 ≥ CTHD		0	0	0	0	0	0	0	1
Z7 < CTHD		0	0	0	0	0	0	1	1
Z7 ≥ CTHD		0	0	0	0	0	0	1	1
Z6 < CTHD		0	0	0	0	0	0	1	1
Z6 ≥ CTHD		0	0	0	0	0	0	1	1
Z5 < CTHD		0	0	0	0	1	1	1	1
Z5 ≥ CTHD		0	0	0	0	1	1	1	1
Z4 < CTHD		0	0	0	1	1	1	1	1
Z4 ≥ CTHD		0	0	0	1	1	1	1	1
Z3 < CTHD		0	0	1	1	1	1	1	1
Z3 ≥ CTHD		0	0	1	1	1	1	1	1
Z2 < CTHD		0	1	1	1	1	1	1	1
Z2 ≥ CTHD		0	1	1	1	1	1	1	1
Z1 < CTHD		1	1	1	1	1	1	1	1
Z1 ≥ CTHD		1	0	0	0	0	0	0	0

High pass filter		K0 . . . K8								
signal level, Zi		Y0	Y1	Y2	Y3	Y4	Y5	Y6	Y7	Y8
Z8 < CTHD		0	0	0	0	0	0	0	0	1
Z8 ≥ CTHD		0	0	0	0	0	0	0	1	0
Z7 < CTHD		0	0	0	0	0	0	1	0	0
Z7 ≥ CTHD		0	0	0	0	0	0	1	0	0
Z6 < CTHD		0	0	0	0	0	1	0	0	0
Z6 ≥ CTHD		0	0	0	0	0	1	0	0	0
Z5 < CTHD		0	0	0	0	1	0	0	0	0
Z5 ≥ CTHD		0	0	0	0	1	0	0	0	0
Z4 < CTHD		0	0	0	1	0	0	0	0	0
Z4 ≥ CTHD		0	0	0	1	0	0	0	0	0
Z3 < CTHD		0	0	1	0	0	0	0	0	0
Z3 ≥ CTHD		0	0	1	0	0	0	0	0	0
Z2 < CTHD		0	1	0	0	0	0	0	0	0
Z2 ≥ CTHD		0	1	0	0	0	0	0	0	0
Z1 < CTHD		1	0	0	0	0	0	0	0	0
Z1 ≥ CTHD		1	0	0	0	0	0	0	0	0

Reference is now made to FIGS. 8 and 9, which present an alternative embodiment of the filter unit, labeled **14'**. In this embodiment, the filters of filter unit 14 are non-linear. It is expected that this type of filtering is more suitable for visual perceptual coding because its picture processing is similar to the perceptual process of the human eye which uses detected details (e.g. texture) and distinguished details,

As in the previous embodiment, filter unit **14'** comprises low pass filter **101**, time aligner **103** and summer **104**, where summer **104** subtracts a low pass filtered version of the original frame from the original frame and produces thereby a high pass filtered frame ΔY_{HF} . Typically, the high pass

US 6,744,818 B2

7

filtered frame comprises the high frequency components that correspond to those details of the frame which have small dimensions. The high pass filtered frame is then filtered by a non-linear filter 99, which produces a processed addition $\Delta Y_{HF}'$ to be added, in a summer 98, to the low pass filtered signal, thereby to produce the filtered signal Y' .

The non-linear filter 99 comprises two switches 100 and 102, two comparators 104 and 106, two dividers 108 and 110, a doubler 112, a squarer 114, four summers 116, 118, 120 and 121 and a variable multiplier 122.

Switch 100 determines the response for texture details and produces a signal ΔY_{SW1} . Mathematically this is given by:

$$\Delta Y_{SW1} = \begin{cases} 2\Delta Y_{HF} - \frac{\Delta Y_{HF}^2}{3\sigma}, & \text{if } |\Delta Y_{HF}| < 3\sigma \\ 3\sigma, & \text{otherwise} \end{cases} \quad \text{Equation 1}$$

where σ is the root-mean-squared (RMS) noise level of the input signal.

Comparator 104 compares high pass filtered signal ΔY_{HF} to the threshold level 3σ to determine the results of the if statement in equation 1. The output of comparator 104 indicates to switch 100 to choose either the output of summer 116 (which is the upper calculation of equation 1) or the value of 3σ , as the other input to switch 100.

Summer 116 receives $2\Delta Y_{HF}$ from doubler 112 and $\Delta Y_{HF}/3\sigma$ or the combined output of squarer 114 and divider 108 (which also receives the threshold level 3σ) and performs the subtraction, thereby creating the signal to switch 100.

Switch 102, together with summer 121, determines the response for details whose signal level is between the detection and distinction threshold. Switch 102 produces a signal ΔY_{SW2} . Mathematically this is given by:

$$\Delta Y_{SW2} = \begin{cases} \frac{\Delta Y_{HF}^2}{\Delta Y_{CTHD}}, & \text{if } |\Delta Y_{HF}| \leq \Delta Y_{CTHD} \\ \Delta Y_{CTHD} \Delta Y_{SL}, & \text{otherwise} \end{cases} \quad \text{Equation 2}$$

where ΔY_{CTHD} is the signal level that corresponds to the compression threshold CTHD and ΔY_{SL} is defined hereinbelow in equation 3.

Comparator 106 compares high pass filtered signal ΔY_{HF} to the threshold level ΔY_{CTHD} to determine the results of the if statement in equation 2. The output of comparator 106 indicates to switch 102 to choose either the output of divider 110 (which is $\Delta Y_{HF}^2/\Delta Y_{CTHD}$) or the output of summer 120 (defined by equation 3 hereinbelow).

For distinguished details, the amplitude response is given by:

$$\Delta Y_{SL} = K_d(\Delta Y_{HF} - \Delta Y_{CTHD}) + \Delta Y_{CTHD} \quad \text{Equation 3}$$

where K_d is an externally provided value which varies between 0 and 1.

Summer 118 takes the difference between high pass filtered signal ΔY_{HF} and the threshold level ΔY_{CTHD} and variable multiplier 122 multiplies the difference by the current value of variable K_d , as provided by a user. Summer 120 adds the threshold level ΔY_{CTHD} to the signal and provides the result to switch 102.

It is noted that the corrected high pass filtered signal $\Delta Y_{HF}'$ is the sum of the outputs ΔY_{SW1} and ΔY_{SW2} of the two switches 100 and 102, respectively. Due to the comparisons with the noise level 3σ and the threshold level ΔY_{CTHD} , the corrected high pass filtered signal $\Delta Y_{HF}'$

8

generally only contains those details that can be perceived by the human eye.

This is indicated in FIG. 9, which illustrates the amplitude response of the filter 14' versus the change in luminance ΔY . The graph of FIG. 9 has three areas, a detection area 140, defined by the noise level 3σ , a distinction area 142, above the threshold level ΔY_{CTHD} , and an in-between area 144. The graph of FIG. 9 also shows two curves, a 45° line, labeled 146, which indicates a signal which is not corrected (i.e. the input equals the output) and a solid line 148 indicating the response of filter 14'.

In the detection area 140, the filter 14' makes only a small change over the non-corrected line 146. In in-between area 144, there is a significant difference between non-corrected line 146 and amplitude response 148. This is because, for details that the human eye can detect but not distinguish, there is little need to encode the pixels of such details in full. In distinction area 142, the slope of amplitude response 148 varies according to the value of the variable K_d . Typically, variable K_d is chosen based on a trade-off between the need for compression (in which case variable K_d can be less than 1) and the need to properly reproduce the detail.

Reference is now made to FIG. 10 which illustrates visual perceptual coding using the nonlinear filter of FIG. 8 for filtering the Y luminance Y and the two chrominances C_r and C_b . Each signal is filtered separately in the X and the Y directions, where the same operations occur for each direction. For each direction and for each signal type, there is a low pass filter (LPF_y^Y , LPF_x^Y , $LPF_y^{C_r}$, $LPF_x^{C_r}$, $LPF_y^{C_b}$ and $LPF_x^{C_b}$) to produce a smoothed signal, a time aligner 130 and a summer 132 to produce the high pass filtered signal (ΔY_{HF}^Y , ΔC_r^Y and ΔC_b^Y) containing the high frequency components, a multiplier 134 to scale the high pass frequency signal (described in more detail hereinbelow) and a summer 136 to add the high frequency elements to the smoothed signal from the low pass filter LPF.

For the luminance signal Y, there is also a non-linear adaptive filter NAF of the type described with respect to FIG. 8, operating on the output of summers 132, to select only the desirable elements of the high frequency signal. The output of the filter NAF is provided to multiplier 134 and the remaining elements are the same as described hereinabove.

Because the ratio of the two chrominances C_r and C_b to the luminance Y must be maintained and because the non-linear filter can affect that ratio, the system of FIG. 10 produces gains K_Y and K_c , to correct for any non-linearities introduced. Gain K_Y is used by multipliers 134 in the luminance path and gain K_c is used by multipliers 134 in the two chrominance paths.

To produce the gains K_Y and K_c , the system of FIG. 10 includes two dividers 140 and 142, a maximum level selector 144, a low pass filter 146 and a shaper 148. Divider 140 divides the luminance high pass filtered signal ΔY_{HF}^Y by the red chrominance high pass filtered signal ΔC_r^Y while divider 142 divides the luminance high pass filtered signal ΔY_{HF}^Y by the blue chrominance high pass filtered signal ΔC_b^Y . Maximum level selector 144 selects the higher value of the outputs of the two dividers 140 and 142 and the output of selector 144 is smoothed by low pass filter 146. The output of low pass filter 146 is the gain K_Y . Shaper 148 produces the gain K_c by inverting the level of the gain K_Y , thus, $K_c = 1/K_Y$.

Reference is now made to FIGS. 11 and 12, which illustrate an alternative embodiment of the present invention. FIG. 11 shows the entire system and is similar to that of FIG. 1 with the addition of a resolution enhancing filter 150 which generally enhances the spatial and temporal

US 6,744,818 B2

9

resolution of the compressed frame produced by filter unit **14** before providing the compressed frame to encoder **16**.

Resolution enhancing filter **150** receives the input and output signals of filter unit **14** as well as the compression dependent threshold CTHD. As shown in FIG. 12, filter **150** comprises a vertical high pass filter **152**, a horizontal high pass filter **154**, a temporal high pass filter **156**, two nonlinear filters **158** and **160**, a variable multiplier **162** and an adder **164**.

Vertical and horizontal high pass filters **152** and **154** have frequency responses similar to that shown in FIG. 3 and operate on the X and Y directions on the input frame from time aligner **18**. Temporal filter **156** is a finite impulse response (FIR) filter operating between frames. Exemplary pulse and frequency responses h_T and HT for filter **156** are:

$$h_T = \{-0.25, 0.5, -0.25\}$$

$$H_T(\omega) = \sin^2 0.5 \omega T$$

where T is the frame period (typically either $\frac{1}{25}$ or $\frac{1}{30}$).

Non-linear filters **158** and **160** receive the output signals of high pass filters **152** and **154**, respectively, as well as the compression dependent threshold CTHD. Filters **158** and **160** are similar to that shown in FIG. 8 and have responses similar to that shown in FIG. 9.

Variable multiplier **162** receives a variable slope K_T defined as:

$$K_T = \frac{1}{CTHD_i}$$

and multiplies the output of temporal filter **156** with a linear function having the slope K_T .

Adder **164** sums the output of filter unit **14** with the outputs of filters **158** and **160** and of variable multiplier **162** and produces thereby the resolution enhanced, compressed frame.

The methods and apparatus disclosed herein have been described without reference to specific hardware or software. Rather, the methods and apparatus have been described in a manner sufficient to enable persons of ordinary skill in the art to readily adapt commercially available hardware and software as may be needed to reduce any of the embodiments of the present invention to practice without undue experimentation and using conventional techniques.

It will be appreciated by persons skilled in the art that the present invention is not limited by what has been particularly shown and described herein above. Rather the scope of the invention is defined by the claims that follow:

What is claimed is:

1. A video encoding system comprising:

a visual perception estimator adapted to estimate a perception threshold for a pixel of a current frame of a videostream;

an encoder adapted to encode said current frame;

a compression dependent threshold estimator adapted to estimate a compression dependent threshold for said pixel at least from said perception threshold and information from said encoder; and

a filter unit adapted to filter said pixel at least according to said compression dependent threshold.

2. A system according to claim **1** and wherein said compression dependent threshold estimator also estimates at least one parameter from the following group of parameters: whether or not a new frame NwFr has been defined by said encoder as an I frame;

whether an ith pixel is in the foreground FG or the background BG of a picture;

10

whether an ith pixel forms part of an edge Ed around an object in the picture;

whether or not the ith pixel forms part of a single detail SD;

whether or not the ith pixel is part of a group Gr of generally periodic details;

the contrast level Lv of the detail for the ith pixel;

the duration τ of a detail within a picture;

how full said encoder is; and

the distance DP of the ith pixel from the center of the frame.

3. A system according to claim **2** and wherein said compression dependent threshold is formed from normalized versions of said parameters and said perception threshold PTHD_i as follows:

$$CTHD_i = \left(\begin{array}{l} PTHD_i + C_E Ed + C_D SD + C_G Gr + C_r N\tau + \\ C_L NLv + C_F NwFr + C_B F/B + C_P DP \end{array} \right) C_V VBF + C_0$$

where C_B, C_D, \dots, C_P are weighting coefficients.

4. A system according to claim **1** and wherein said filter unit is a controllable filter set adapted to select a filter for said pixel according to said compression dependent threshold.

5. A system according to claim **1** and wherein said filter unit is a non-linear filter.

6. A system according to claim **5** wherein said non-linear filter comprises:

a low pass filter;

a high pass filter whose output is a signal ΔY_{HF} ;

a first switch SW1 whose output is defined as:

$$\Delta Y_{SW1} = \begin{cases} 2\Delta Y_{HF} - \frac{\Delta Y_{HF}^2}{3\sigma}, & \text{if } |\Delta Y_{HF}| < 3\sigma \\ 3\sigma, & \text{otherwise} \end{cases}$$

where σ is the root-mean-squared (RMS) noise level of the input signal to said filter unit;

a second switch SW2 whose output is defined as:

$$\Delta Y_{SW2} = \begin{cases} \frac{\Delta Y_{HF}^2}{\Delta Y_{CTHD}}, & \text{if } |\Delta Y_{HF}| \leq \Delta Y_{CTHD} \\ \Delta Y_{CTHD} \Delta Y_{SL}, & \text{otherwise} \end{cases}$$

where ΔY_{CTHD} is the signal level that corresponds to the compression dependent threshold CTHD and ΔY_{SL} is defined as:

$$\Delta Y_{SL} = K_d (\Delta Y_{HF} - \Delta Y_{CTHD}) + \Delta Y_{CTHD}$$

where K_d is an externally provided value which varies between 0 and 1; and

a summing unit which sums the output of said first and second switches with the output of said low pass filter.

7. A system according to claim **1** and wherein said filter unit includes at least one nonlinear filter unit and a chrominance correction unit.

8. A system according to claim **7** and wherein said chrominance correction unit includes means for maintaining the ratio of two chrominances C_r and C_b to luminance Y .

9. A system according to claim **1** and also comprising a resolution enhancing filter which generally enhances the resolution of the output of said filter unit.

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